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Review on the Effect of Gibberellic Acid on Potato (Solanum tuberosum L.)Tuber Dormancy Breaking and Sprouting

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Abstract
Gibberellins are growth promoters and to date over hundred gibberellins have been isolated and mainly produced in the leaves but may also be synthesized in the root and fruits, but not all are active in plants. Gibberellic acid is a naturally occurring plant growth regulator which may cause a variety of effects including the stimulation of seed germination by breaking seed dormancy. Gibberellins influence the dormancy of seeds, shoots, and other plant parts. In potato, a condition often physiological rest prevails from the time of tuber initiation until 6 to 12 weeks after harvest depending on varietal characteristics. The rest period has been markedly curtailed by immersing freshly harvested potato tubers in gibberellins. This effect, coupled with the rapid stimulation of growth of various plants by gibberellins, suggested that pre-harvest foliar sprays of this chemical might shorten the rest period of the immature, developing tubers. Gibberellins also initiate the sprouting process of the tubers on the plant when sprouting is least likely. Both pre and post harvest treatments, have effect on breaking dormancy, early emergence of shoots, increased tuber yield and quality of potato Haulm applications of GA3 at 750 and 1000 ppm reduced dormancy period by 24 days and 27days, respectively. It also hastened early physiological maturity, increased average sprout number and sprout length of tubers, respectively. Similarly, dipping treatment of 40 and 50 ppm reduced dormancy period by 18 days and 20 days, respectively, and had more effect over the control than lower concentrations. Haulm application of 750 or 1000 ppm reduced days to emergence by 11 days while dipping of seed tubers in 40 and 50 ppm reduced days to emergence by 6 and 8 days, respectively, haulm applications of GA3 at a rate of 750 ppm or dipping tubers in 40 ppm GA3 solution were found to be optimum

1. Introduction

Potato (*Solanum tuberosum* L.) is a member of the nig family (*Solanaceae*). It is the major world food crop and by far the most important food crop in terms of quantities produced and consumed worldwide, ranking fourth (309 million metric tons/year) after maize ,rice and wheat, with an estimated production area of 18.5 million hectare at an average yield of 16.7 tons/ha (FAOSTAT, 2007). The production and consumption of potato is growing in the developing world whereas it is decreasing in the developed world (Keijbets, 2008). Potato is an important food and cash crop in eastern and central Africa, playing a major role in national food security and nutrition, poverty alleviation and income generation, and provide semployment in the production, processing and marketing sub-sectors (Lung`aho *et al*., 2007).

Potato tubers give an exceptionally high yield per area and are used in a wide variety of table, processed, livestock feed, and industrial uses (Feustel, 1987;Talburt, 1987).Potato contains about 16% carbohydrates of which starch constitutes about14% of the fresh weight (Azimuddin *et al*., 2009). It has been identified as a cheap source of human diet since it produces more food value per unit time in terms of carbohydrates, high quality protein (lysine), mineral nutrients, salts and several vitamins from group B and large amount of vitamin C (Kolasa ,1993). Furthermore, there are evidences indicating that potatoes contain significant levels of important antioxidants, including phenolic acids, flavonoids, and carotenoids, among others (Yamamoto *et al.*, 1997; Lachman *et al.*, 2000).Due to these merits and its starch value, it provides three to four times more calories per unit area as compared to cereals and is an ideal food for supplementing cereal-based diets(Nyende*etal*.,2005). Owing to its aforementioned merits, potato ranks first in the expansion of production in the developing countries (Horton,1987).The potato crop was introduced to Ethiopia around 1858 by Schimper, a German botanist(Pankhurst, 1964).

Unlike its long history of cultivation and in spite of the existence of suitable climatic and edaphic conditions in the c country, potato production as well as productivity is low. Ethiopia is endowed with suitable climatic and edaphi c conditions for quality potato production. About 70% of the available agricultural land is located at an altitude of 1800-2500 m.a.s.l and receives an annual rain fall of more tha600mm,whichissuitable for potato production (Solomon, 1987).Potato is the second most important tuber crop grown in the country next to 'Enset' (*Enseteventricosum* L.) in terms of area coverage (Girma, 2001). The current area under potato production in Ethiopia is about 73,095 hectares with an average national yield of 10 tons per ha for the main cropping season (CSA, 2007). It has now become an important food and cash crop in Ethiopia, especially in the high and mid altitude areas. It also has promising prospect in improving the quality of the basic diet in both rural and urban areas of the country (Bergae*t al*., 1994). As a food crop, it has a great potential to supply high quality food within a relatively short period and is one of the cheapest sources of energy. According to Stevenson *etal*.

(2001) potatoes produce 54 percent more protein per unit of land area than wheat and 78percent more than rice. They also reported that no other food, not even soybean, can match the potato for production of food energy and food value per unit of land area. Such a crop undoubtedly is very important for countries like Ethiopia, where inadequate protein and supplies of calories are the apparent nutritional problems (Berga *et al*., 1994).Many diverse and complex biotic, abiotic, and anthropogenic factors have contributed to the existing low productivity of potato in Ethiopia. Among others, poor growing practices, lack of good quality planting materials, low use of inputs, poor control of disease and pests, improper time of planting and harvesting, rigid traditional food habit of the people and poor soil management practices can be mentioned as major constraints (Berga *et al.*, 1994;Lung`aho *et al*., 2007). The potential attainable average yields of the crop on research and farmers' fields are 45 and 25 tons/ha, respectively while the current national average production is limited to about 10 tons/ha (MoARD, 2005; CSA, 2007). In Sub-Saharan African countries the yield is around 8 tons/ha on the continent compared to a world average of 16 tons/ha (FAOSTAT, 2008). The gap between the attainable potential yield and the current average national yield could be attributed to different factors, among which lack of quality seed tubers is the most important one. The improvements of crop productivity in modern agricultural systems are increasingly dependent on manipulation of the physiological activities of the crop by chemical means (Subhadrabandhu *et al*., 1999). The management of potato tuber dormancy is of great importance for the ware, packing and processing markets and also for the seed industry. After harvesting, potato tuber is naturally dormant for 1-15 weeks depending on the cultivar and storage conditions (Wiltshire and Cobb, 1996).

As the authors stated, if potatoes are to be stored they first go through a curing process for about two weeks in which they are held at 10-15°C. This allows surface drying, periderm formation and wound healing. After curing, store management depends on the intended end market, the cultivar being stored and the facilities available.

Depending on the intended purpose, accelerated (i.e. seed tubers) or delayed (i.e. ware potato, industrial processing) sprouting of the harvested tubers is favorable. As with many aspects of plant development, plant hormones have been playing a primary role in the regulation of potato tuber endodormancy (Rappaport and Wolf, 1969; Hemberg, 1985). Four of the five principal classes of plant hormones abscisic acid, cytokinins, gibberellic acid, and ethylene have been implicated in dormancy regulation (Hemberg, 1985; Suttle, 1996; Wiltshire andCobb, 1996). It has been hypothesized that dormancy is regulated by the relative concentrations of growth promoters and inhibitors. Gibberellins and cytokines are generally considered to be growth promoters, whereas abscisic acid and ethylene are believed to inhibit sprout growth (Sonnewald, 2001).Endogenous hormones have been proposed to play a significant role in tuber dormancy regulation (Suttle, 2004). The level of endogenous GAs remains low during the middle period of storage (deep dormancy) and increase near the onset of dormancy (Bruinsma *et al*., 1967).Thus, exogenous application of GA3 is used to break potato tuber dormancy (Hemberg, 1958;Rappaport *et al*., 1957) and it is commercially used to break dormancy of potato tuber. Dipping or soaking of tuber in to GA3 solution on wounded tuber break the dormancy of tuber (Hemberg, 1958; Rappaport *et al*., 1958). According to (Lippert *et al.,* 1958; van Ittersum *etal*., 1993) GA3 is also applied on haulm to shorten the dormancy of potato and stimulate sprout initiation in a short period of time. Moreover, haulm application of GA3 two weeks prior to vine killing and dipping the tubers in GA3 solution shorten the dormancy period (Bruinsma *et al*., 1967). Use of chemicals to regulate dormancy is a common practice in many countries. Being environmentally friendly and less toxic, GA3 treatment is widely used in many countries for breaking tuber dormancy (Alexopoulos *et al*., 2008).Lack of good quality seed among growers is the major problem adversely affecting the expansion of potato production in many developing countries (Shibairo *et al*., 2006). One major problem facing production of quality potato seed is poor sprouting, due to dormancy, which leads to delayed planting and poor crop emergence and vigor (Wiersema, 1985).

Timely availability of well-sprouted seed tubers at the on-set of rain as well as for irrigation is a pre-requisite for attaining proper planting materials which leads to high yields. Due to unavailability of sprouted tubers for planting at desired time, small scale farmers often promote potato sprouting by placing them in pits, sacks, teff straw and trenches and use genotypes with short dormancy. Medium to long dormancy genotypes are thus not easy to incorporate in the predominant cropping system in which farmers retain seed from the previous harvest for replanting the next season. Farmers mostly prefer various traditional storage methods to enhance sprouting. Potato seeds sprouted in traditional ways are, however, of poor quality due to apical dominance, rotting and sprout etiolation caused by the dark conditions.

Under Ethiopian condition, the utilization of chemicals to regulate potato dormancy is not common. This is attributed to the lack of information regarding suitable chemicals, and the in methods, rates, and time of application for efficient use. Hence, introduction of chemical that induces dormancy breaking is vital to have early seed planting materials. Of the commercially available plant hormones, GA3 is widely used to break potato dormancy and it can be employed under Ethiopian condition. However, the efficient method of application and optimum rates of GA3 must be identified, and its influence on the subsequent performance of the crop should be studied.

2. Potato Origin and Distributions

Potato is believed to have originated in the high lands of South America in the vicinity of Lake Titicaca near the present border of Peru and Bolivia (Horton, 1987; Rowe, 1993).It comprises about 2000 species of which only less than 10% are tuber bearing (Vos, 1999). Dueto its large genetic diversity the tetra ploid potato genotypes that are grown today have a genomic constitution of 2n = 4x = 48. With a base (x) number of twelve and the wild species occurs as diploids, triploids, tetraploids, pentaploids, and hexaploids, whilst the cultivate desires extends to penta ploids only (Hawkes, 1978). This diversity explains the wide spread cultivation of potato, while individual cultivars appear best suited to specific environments (niches) (Vos, 1999). The crop is grown throughout the world but is of particular importance in temperate climates (FAO, 2005). It is grown in about 140 countries, more than 100 of which are located in the tropical and sub tropical regions (Beukema and Van der Zaag, 1990).As the highest yielding crop per hectare of arable ground, world potato production continues to increase in total amounts as the amount of arable land per capita is decreasing (Coleman,2000). Due to its high nutritive value, potato is cultivated worldwide in the temperate and subtropical zones. Potato is a staple food and is one of the top four crops in the world. The majority of potato production is for human consumption (50–60%); the rest is used as animal feed, for industrial products, or as seed tubers (Sonnewald, 2001). Even though potato is commonly consumed fresh, tubers are versatile and can be used frozen, fried or dehydrated among other derived foods. Due to these merits, potato ranks first in the expansion area of production in the developing world (Horton, 1987; Sonnewald, 2001).Potato is an annual, herbaceous plant, which can be propagated sexually by botanical seed and asexually (vegetative) by means of tubers (Beukema and Van der Zaag, 1990). Potato tubers are shortened and thickened modified storage organs that form at the tips of underground stems (solons) containing several buds in localities commonly referred to as “eyes” (Devlin,1975; Viola *et al.*, 2007). The physiological status and health of seed tubers are among the most important factors influencing potato yield (Wiersema, 1984). Potato needs about 15% of its area to produce the required seed tubers (Lommen, 1995; Struik and Wiersema, 1999) while for cereals only one thirtieth of their area is necessary for seed production.

2.2. Potato Tuberization

Potato tuberization is a complex developmental process known to be influenced by genetic, environmental and physiological factors (Vreugdenhil and Struik, 1989). Available evidence indicates that photoperiod, temperature, irradiance and physiological age of the mother tuber affects tuberization either directly or indirectly by mediating changes in hormone concentrations (Van der Zaag and Van Loon, 1987; Vreugdenhil and Struik, 1989; Ewing,1990). The process of tuberization involves the cessation of growth in the stolon apical meristem and the induction of first longitudinal and later random cell division and expansion in the sub-apical region (Xu *et al*., 1998). This is accompanied by massive deposition of storage carbohydrates (Visser *et al*. 1994) and proteins (Shewry, 2003) in the tubers. If a whole tuber or piece of tuber containing one or more eyes is planted, the buds sprout and a plant develops above the ground. Well before plant emergence the developing sprout grows adventitious roots, which constitute the root system. The underground portion also grows in to stem called stolons, which may bear new tubers at their tips (Ewing, 1997). Moreover the newly formed potato tuber does not sprout even under favorable conditions because of dormancy (Suttle, 2007).

2.3. Potato Tuber Dormancy

Bud dormancy is a characteristic prevalent in many plant species. It can be initiated by various factors, including moisture stress, high or low temperature, day length, hormonal imbalance and heredity (Hartmann *et al*., 2002). There is no universally accepted definition of dormancy. Hemberg (1985) defines dormancy as the collective stage where a bud will not sprout because of endogenous or exogenous conditions. The author refers to the phase of endogenous dormancy as the rest period, but it is also defined as innate or deep dormancy. As such, dormancy is considered as a survival mechanism and potato tuber dormancy is thought to begin on or about the time of tuber initiation (Burton, 1989).The potato tuber is a modified stem (Coleman, 1987) that has developed an end dormant phase to protect it against conditions in which the plant will not survive. Dormancy is defined as the period during which bud growth will not occur even under favorable conditions (Lang*et al*, 1987; Suttle, 2009). It can also be defined as a lack of growth due to the physicochemical condition of the tuber, which is influenced by a number of factors including plant hormones and storage temperature (Burton, 1963). Dormancy is one of the most important physiological properties of seed tubers (Harris, 1992; van Ittersum, 1992). Burton (1989) suggested that the duration of dormancy should be calculated from the time the tubers are. initiated until sprouting commences. It begins during tuber formation when the apical meristem of the stolon no longer gives rise to longitudinal growth, whereas the sub-apical parts take over, resulting in radial growth and producing the final tuber (Vreugdenhil, 2007).Claassens and Vreugdenhil (2000) mentioned that dormancy gradually develops in the tuber from the moment cell division in the stolon tip has stopped and the tuber starts to develop. At harvest, and for an indeterminate period thereafter, potato tubers are dormant and exhibit no meristem (eye/bud) growth (Burton 1989; Suttle, 2007). Thus, dormancy of tuber buds is an intriguing phenomenon, since the buds contain a

complete meristem, appear to be well supplied with nutrients, and yet they don't sprout even when temperature and other environmental conditions are favorable. Because tuber dormancy results from factors arising within the affected organ itself and not from external causes (e.g. correlative inhibition or environmentally imposed quiescence), it is more properly classified as endodormancy (Lang*et al*., 1987). The duration of tuber endodormancy varies and depends on both the cultivar (i.e. genetic background) and, to some extent, the environmental conditions during tuber development (Burton, 1989). Fresh potato tubers are in the state of endogenous dormancy, which must be terminated before sprout growth will occur. Breaking of tuber dormancy is therefore important for seed potato multiplication, rapid post harvest disease testing and early production in the field or greenhouse (Coleman, 1983).

During the resting state, the potato tuber must undergo certain physiological changes to break dormancy and allow the potato tuber to sprout. At the end of the dormant period, the apical meristem becomes active again, and sprouting commences. Hence, tuber formation and the breaking of dormancy have been described as opposite phenomena. Wiersema (1985) found that crops from physiologically young seed tubers produce fewer stems, have latertuberization, more foliage and more tubers per stem than crops from physiologically old seed tubers. Use of low quantities of growth promoters such as thiourea, rindite, carbon disulphide and bromoethane (Bryan, 1989) and gibberellic acid (Carrera *et al*., 2000; Demo *et al*., 2004)to promote potato seed sprouting has been suggested. (Alexopoulos *et al*., 2008).Botanically, the tuber is a highly compressed stem, and the eyes correspond to apical and lateral axillaries buds. Tubers are vegetative over-wintering organs and According to the author dormant organs are typically more resistant to biotic and abiotic stresses. Dormancy in potato tubers has been defined as the period during which no visible

Development of buds is observed even under conditions that are favorable for sprouting (Reust, 1986). When tubers are intended for consumption, a long period of dormancy is desirable so as to increase the storage life. In the case of seed tubers breaking dormancy earlier is for commercial potato production using irrigation, however, a short dormant period is preferred so as to encourage rapid sprouting. In general, rates of many cellular processes such as respiration, transcription, and translation are suppressed during dormancy (Macdonald and Osborne, 1988). However, around the onset of sprout growth which follows dormancy termination are accompanied by substantial increase in cell metabolism. Understanding and controlling potato tuber dormancy and sprouting are essential for production, processing and fresh markets. For different markets, the aims might either be to delay sprouting, or to accelerate sprouting.

2.4. Factors Affecting Tuber Dormancy

Several factors have been suggested to be involved in potato tuber dormancy. The natural period of dormancy is dependent on genetic and pre-and post-harvest environmental factors (Burton, 1989; Claassens and Vreugdenhil, 2000; Suttle, 2008). Hormones, defined as low molecular weight (mobile) compounds that influence growth and development in low concentrations, have often been suggested to play a crucial role in breaking potato dormancy(Vreugdenhil, 2007). The duration of tuber dormancy is affected by the environmental conditions that exist during tuber development on the mother plant and during storage, where temperatures lower than 10°C delay dormancy breakage and sprout development (Burton,1989).In addition to environmental extremes, tuber dormancy can be prematurely terminated by a variety of chemicals treatment whose mechanism of actions are not well known. Several of these agents like gibberellic acid, rindite, ethylene, thiourea, carbon disulphide (CS2), and bromoethane are used to stimulate sprout initiation and growth of potato tubers (Coleman, 1987; Allen *et al*., 1992). Although dormancy is defined as the absence of visible growth, dormant meristems are metabolically active. Length of dormancy period depends on the varieties, maturity of the tuber, soil and weather conditions during growth, storage conditions and whether the tuber has damaged or not. Growth conditions during seed production (especially temperature, photoperiod, light intensity, and nitrogen fertilization) can also affect the duration of dormancy (van Ittersum, 1992). Similar investigation also suggested that, the length of potato dormancy period is dependent on the genotype as well as on both pre- and post-harvest conditions

2.4.1. Genetic variation

Dormancy of potato varies among genotypes. It may also vary within a seed lot of one cultivar from a particular origin or year. The survival advantage, the inheritance pattern of tuber dormancy is complex, and it is controlled by at least nine distinct loci (Van den Berg *et al*., 1996). In many potato cultivars, natural dormancy progression occurs over a period of many months. Usually, the dormant period is shorter in early cultivars than in later cultivars(Harris, 1992), although this relation is not very strict (Burton, 1968). Bachem *et al*. (2000) investigated that major changes in gene expression occur during dormancy progression. Although their relationship to dormancy is unclear, a number of transcripts and proteins unique to either dormant or growing meristems have been identified.

2.4.2. Growing conditions

The length of dormancy period in any given variety is not constant and it varies from year to year, in addition to which the place of cultivation may influence the dormancy period (Struik and Wiersema, 1999). Potato grown in

short day tends to have a shorter dormancy period. The duration of the dormancy period varies among and with condition during growth (White,1983). The temperature at which the potato grown; however, have a far greater influence on the length of dormancy (Scholte, 1986). According to Struik and Wiersema (1999) potatoes grown at higher temperature particularly at the end of growing period have shorter dormancy.They also found that growing conditions during the tuber production affect the dormancy and physiological age after harvest, even if much less than storage conditions after harvest. Photoperiod, temperature, light intensity, and nitrogen fertilizer all have significant effects. On the other hand, soil conditions after haulm destruction but before harvest probably have the largest effect (Struik and Wiersema, 1999).

2.4.3. Storage conditions

Environmental factors during storage affect physiological age. Relevant factors include relative humidity, temperature, photoperiod, and diffuse light (Scholte, 1986; Struik andWiersema, 1999). Especially the temperature effect is highly complex and cultivar specific. As metabolic processes and physiological events taking place before and after dormancy differ, the sensitivity towards environmental conditions, and especially towards temperature, during the different stages of physiological development of the seed tuber may also vary(Scholte, 1986; Struik and Wiersema, 1999; Struik *et al*., 2006). Heat shocks, cold shocks, and similar accumulated day-degrees built up in different ways may all have their specific effects, depending on cultivar (van Ittersum, 1992; Struik and Wiersema, 1999; Struik *et al*.,2006). Struik and Wiersema (1999) described that diffuse light may prevent rapid ageing of seed tubers.

These authors stated that positive effect is realized both by effects on the development of the sprouts and on the condition of the mother tuber. They mentioned that the positive effect of prolonged exposure to light is cultivar specific and depends on storage temperature and photoperiod. At a temperature of 16°C growth vigor of seed tubers remains highest under long days, whereas at 28°C growth vigour decreases much faster under long days than under short days (Struik and Wiersema, 1999).

Temperature

Dormancy can be shortened by warm storage (Struik *et al*., 2006) but also by a short treatment of heat (van Ittersum, 1992) or in some cultivars also by a short treatment of cold storage (van Ittersum and Scholte, 1993b). Struik and Wiersema (1999) reported that the optimum temperatures for dormancy break and sprout growth differ such that the optimum temperature is higher for dormancy break than for sprout growth. They also mentioned that with an increase in storage temperature, the breaking of dormancy is faster. However, storage temperature also affects sprout growth on tubers that are no longer dormant. Prolonged storage at 4°C results in more sprouts per seed tuber (Struik and Wiersema, 1999).Burton (1989) suggested that the length of tuber dormancy is inversely proportional to storage temperatures when storage temperatures are between 3°C to 25°C. The author mentioned several factors that can influence temperature management for stored potatoes.

Light

Light generally inhibits sprout growth and contributes to dormancy enforcement. This effect is well characterized and is commercially in management of seed tubers. The degree of growth inhibitor is related to wave length, light with wave length below 500 nm (blue) and above 650 nm (red and far red) have the greatest inhibitory effect (McGee *et al*., 1987).Traditionally, farmers store their potatoes at home in a dark room to prevent their produce from greening. These are used as seed potatoes for the next planting, as well as for sale and home consumption. However, dark storage can be a problem in the warmer lowland and coastal areas, because it can increase losses by insects and excessive sprouting (Andrew,2001).

Humidity

Humidity is of little importance in the consideration of tuber dormancy. There have been few reports on this subject probably because changes in humidity with in ambient range are likelyto have only small effect on tuber water states and such small effect on tuber quality especially in the case of new potato. Tuber quality has been associated with sucrose compartment in parenchyma cells (Oparkar *et al*., 1990). They also suggested that, it is better to maintain the tuber at 95% relative humidity at all times.

Carbon dioxide and Oxygen concentrations

An increase in CO2 concentration in the storage atmosphere is reported to shorten the dormancy period of potato tubers (Burton, 1968). Treatment with 20% CO2 for 7 days was found to be as efficient as rindite treatment for breaking tuber dormancy (Reust and Gugerli 1984). Enhanced dormancy release was observed with a 7-day treatment with 20% CO2 by Coleman and McInerney (1997). The ability of higher concentrations of CO2 to break dormancy has resulted in the exploration of a possibility of using this as an alternative to chemical treatment. Similar studies indicated that CO2 and oxygen (O2) concentrations alone apparently have little effect on innate dormancy but dose influence sprout growth (Burton,1989). According to Esashi (1992) dormancy is released in dormant potato tuber where high concentrations of CO2 and O2 have been observed repeatedly, although the specific physiological mechanisms are not well known. Similarly, Wiltishire and Cobb (1996) found that in potatoes, tuber dormancy could be broken effectively with 40- 60% CO2 and 20% O2 ethylene production (Esashi, 1992), which also plays a vital role in dormancy release and sprouting (Rylski *et al*., 1974).

Physiological age of the seed tuber

Tuber yield in potato is strongly influenced by seed quality. Important seed quality characteristics are: seed tuber size, physical characteristics such as shape and presence of wounds, physiological age and seed tuber health. Physiological age of seed potatoes strongly affects emergence, number of stems per plant, number of tubers per stem, tuber size distribution and tuber yield of the progeny crop (Van der Zaag and Van Loon, 1987; vanIttersum, 1992; Struik and Wiersema, 1999). Krijthe (1962) and van Ittersum (1992) demonstrated that both mother tuber age and sprout age affect the performance of a seed tuber. Van Ittersum (1992) found that until breaking of the dormancy changes in the physiological status of the seed are only reflected by biochemical and physiological changes in the seed tuber itself and not by morphological changes. After dormancy breaking the physiological age is still influenced by the age of the mother tuber, but modified by the additional effects of conditions and treatments on the behavior of the sprouts (Caldiz *et al*.,2001). However, the evidence for these separate effects from experimentation is still scarce.

As a seed tuber age tends to have a shorter dormancy period, emerges earlier, produces multiple stems, initiates tubers earlier at a lower leaf area index, produces less vine growth, senesces earlier, and produces more tubers but of smaller size (Caldiz *et al*., 2001). Yields may or may not be compromised depending upon length of season and the intended use of the harvested crop (Olsen *et al*., 2002).The physiological age needs to be optimized to produce a canopy and a tuber system that allow tuber production for specific outlets (Struik *et al*., 1990, 1991).

Injury

Tubers attacked by micro-organisms, insect and mechanically damaged (also by cutting) or wounding have a shorter dormancy period than healthy and undamaged tubers. Cutting and injuring seed tubers can break tuber dormancy and shorten the period of dormancy (Struik and Wiersema, 1999). Tubers are often bruised and cut during harvesting and pre storage handling. Regardless of how the stored potatoes are to be marketed, wound healing is essential to minimize the entry areas for ever present disease causing organisms.

2.5. Dormancy Breaking and Sprouting

In order to terminate premature dormancy and induce sprouting there are diverse range of physical, chemical and hormonal treatments (Burton, 1989; Coleman, 1987; Suttle, 2009). With the possible exception of the hormonal treatments, the internal mechanism(s) through which these treatments act is (are) unknown. By determining common effects of these diverse agents, it may be possible to identify central processes critical to dormancy progression in tubers. A number of exogenous chemicals can remove dormancy from field grown tubers (Coleman, 1987; Wiltshire and Cobb, 1996), but similar evaluation for micro tubers have been limited.

2.5.1. Chemicals used to break dormancy of potato tuber

The starting moment of tuber formation is of importance for length of sprouting period. Sprouting can be stimulated by treating the tuber with different chemical, increasing the humidity of storage atmosphere, by variations the storage temperature. Rindite, carbon disulfide, and gibberellic acid are widely used to break potato dormancy (Rehman *et al*.,2001). These authors stated that the main disadvantage of the first two compounds is their toxicity to human health and the environment. As a result, gibberellic acid is preferred and is being used more commonly than the two.

Gibberellic acid (GA3)

Gibberellic acid (also called Gibberellin A, GA, and GA3) is a hormone found in plants. Its chemical formulae is $C_{19}H_{22}O_6$ with a molecular mass of 346.38 g/mol and melting point of 233 - 235°C when purified; it is a white-to-pale-yellow crystalline powder, soluble in ethanol and slightly soluble in water (Raven *et al.*, 2005). Gibberellins are growth promoters and to date over hundred gibberellins have been isolated and mainly produced in the leaves but may also be synthesized in the root and fruits (Vivanco and Flores, 2000), but not all are active in plants.

Table 1. Effect of gibberlic acid on length of potato tuber dormancy period, average number and length of sprout

Treatments	Dormancy period(days)	Average number of sprout(count)	Average length of sprout(mm)
Control(Ethanol and DDW)	**106**	**2**	**78**
Haulm application of 250ppm GA3	**94.67**	**4**	**80**
Haulm application of 500ppm GA3	**85.33**	**4**	**90**
Haulm application of 750 ppm GA3	**82.33**	**4.33**	**92**
Haulm application of 1000ppm GA3	**79**	**5.33**	**93**
Dipping tubers in10ppm GA3	**98**	**2.67**	**55**
Dipping tubers in10ppm GA3	**97.67**	**3**	**70**
Dipping tubers in20ppm GA3	**95.6**	**3.33**	**80**
Dipping tubers in 30ppm GA3	**87.67**	**3.67**	**86**
Dipping tubers in40 ppm GA3	**86**	**4**	**88**
Mean	**91.27**	**3.63**	**78**

Source Abebe,(2010)

Gibberellic acid is a naturally occurring plant growth regulator which may cause a variety of effects including the stimulation of seed germination by breaking seed dormancy. It occurs naturally in the seeds and tubers of many species and is produced commercially by growing *Gibberella fujikuroi* fungus culture in vats, then extracting and purifying the GA3 (Takahashi*et al*., 1991). According to Lippert *et al*. (1958) gibberellins influences the dormancy of seeds, shoots, and other plant parts. These authors reported that in potato, a condition of physiological rest prevails from the time of tuber initiation until 6 to 12 weeks after harvest depending on varietal characteristics. Moreover, they suggested that the rest period has been markedly curtailed by immersing freshly harvested potato tubers in gibberellins. They found that this effect, coupled with the rapid stimulation of growth of various plants by gibberellins, suggested that pre-harvest foliar sprays of this chemical might shorten the rest period of the immature, developing tubers. Gibberellins also initiate the sprouting process of the tubers on the plant when sprouting is least likely.

As reported by Brian *et al*. (1955) and subsequently confirmed by others (Rappaport *et al*.,1958; Hemberg, 1985), tuber dormancy could be broken with exogenous treatment of gibberellins (GAs). As these authors mentioned GA (typically GA3) is often used in seed certification programs where rapid replanting of seed tubers is required for pathogen testing. Similar investigations indicated that, seed potato tubers treated with GA3 immediately after harvest gave better emergence and tuber yield than those treated 24 hrs before planting (Mondal and Chatterjee, 1986). Struik *et al*. (1989) investigated that soil application and foliar application of gibberellic acid have similar effects on shoot, stolon and tuber formation and hence the result in higher yield of the shoot, longer plants, smaller leaves, more branching, change in rate of development of the potato plant, longer stolons, and increased fresh yield of owing to their less toxicity and effectiveness, gibberellic acids are the most commercially used chemical to stimulate early sprouting of potato tuber. The level of endogenous GA3 remains low during the rest period and increased during the onset of sprouting (Rapport,1967).

Rindite

Promoting early establishment in potato tubers may be achieved by chemical treatment. Rindite (7:3:1 anhydrous ethylene chlorohydrin: ethylene dichloride: carbon tetrachloride), carbon disulphide and gibberellic acid have been used to break potato tuber dormancy and to hasten sprouting (Denny, 1984; Claassens and Vreugdenhil, 2000). However, chemical treatments such as Rindite, pose high toxicity risks, both for the workers handling the chemicals and for the environment (Rehman *et al*., 2001). Rindite was used extensively by the formal seed production system to break potato seed tuber dormancy and promote sprouting. Though very effective, Rindite is

toxic thus environmentally unfriendly and damaging to human health (Rehman *et al*., 2001) and hence its use is discouraged. Rindite is the effective dormancy release for microtubers and field tubers; however, as stated above, their mutagenecity, carcinogenicity and toxicity make their commercial use unacceptable (Wattimena, 1983; Kim *et al*., 1996, 1997). The use of bromoethane vapor in conjugation with a carbon dioxide, oxygen and ethylene treatment was highly effective in dormancy release in micro tubers and may provide a more environmentally-acceptable alternative for micro tubers, greenhouse and field grown tubers (Coleman *et al.,* 1992; Coleman, 1998; Coleman and Coleman, 2000). Similar investigation reported that, dormancy release was the key factor influencing micro tuber performance. Rindite proved to be a much more effective dormancy breaking treatment than gibberellins (Pruski *et al*., 2003).

Auxin

Auxins are essential cognate regulators of cell cycle progression in all plant tissues (Francis and Sorrell, 2001). The authors mentioned that, such threshold levels of auxin such as indole- 3-acetic acid (IAA) would be required for sprout growth, but would not be the initiators of dormancy. Thus, auxins do not affect dormancy itself, but influence the growth of sprouts after dormancy has been broken (Alexopoulos *et al*., 2007a). The endogenous levels of auxin such as IAA are low in endodormant potato tubers and increase in shoot buds prior to the onset of growth (Suttle, 2004). The author mentioned that, at relatively high doses exogenous auxins such as IAA and the more stable 1-naphthalene acetic acid were found to be potent inhibitors of sprout growth.

Cytokinins

Cytokinins can enhance micro tuberization (Wang , 1985) as well as modify tuber dormancy duration depending on cultivar (Wattimena, 1983). According to Turnbull and Hanke (1985a) during tuber growth, zeatin riboside was the predominant cytokinin detected in all tissues. However, immediately after harvest, the total cytokinins concentration fell dramatically in the storage tissue, largely as a consequence of the disappearance of zeatin riboside. They also found that during storage, levels of cytokinin in the storage tissue remained relatively constant, but increased in the tuber buds. Moreover, in the buds of tubers stored at 2°C there were a 20 to 50 fold increase in total cytokinin over 6 weeks, coinciding with the natural break of innate dormancy. In field grown tubers, exogenous cytokinin can break dormancy (Hemberg, 1970) with greatest efficacy when applied near the end of the dormancy period (Turnbull and Hanke, 1985a) as the concentration of endogenous cytokinin begins to increase (Turnbull and Hanke, 1985b). Cytokinin induces cell division and cell expansion in sprout within 48 hrs of cytokinin injection (Sukhova *et al*., 1993). These authors examined Kinetin and Zeatin is known to break dormancy in potato tubers.

Ethylene

Ethylene is a naturally occurring gaseous plant hormone. It is believed to be involved in the modulation of a number of potato tuber biochemical pathways and processes such as sprouting and sprout elongation (Strom, 2007). The author stated that in general, ethylene or ethylene releasing compounds like ethephon enhance release from dormancy and increases sprouting of potato tubers. The author also suggested that, ethylene or ethylene releasing compounds also inhibit sprout elongation, which in turn makes ethylene treatment undesirable for rapid crop establishment. Ethylene production increases as sprouting commences and certain dormancy terminating agents stimulate ethylene production (Akoumiankis *et al*., 2008;Suttle, 2008; 2009). It is therefore possible that endogenous ethylene mediates the sprout inducing effects of the dormancy terminating agents. Depending on the concentration and duration of exposure, exogenous ethylene can either hasten or delay tuber sprouting.

Other growth substances

Several researchers mentioned that rather than plant growth regulators various growth substances were also suspected to influence potato tuber dormancy. Some of these are; phenolic compounds, Jasmonic acid /Tuberonic acid/, Brassinosteroids (BS) and volatile compounds. Holst (1971) reported that potato periderm is a rich source of phenolics, and the original extracts assayed for inhibitory activity on dormancy control. Another study has demonstrated that the loss of tuber dormancy is accompanied by a reduction in phenolic acid content and an increase in phenolic conjugate levels (Cvikrova *et al*., 1994). According to Ewing (1995), tuberization is a photo periodically sensitive developmental process that is stimulated under short days by leaf-derived factors. Current evidence suggests that one of these leaf factors is a jasmonic acid derivative given the trivial name tuberonic acid (Yoshihara *et al*., 1989) and the role of jasmonates in tuber dormancy inception and control is unknown. Abdala *et al*. (2000) found that endogenous contents of jasmonic acid have been measured in developing tubers and elongating sprouts and the role of jasmonates in tuber dormancy has not been determined.

Brassinosteroids (BS) are a class of endogenous plant growth substances and were originally isolated from rapeseed pollen as growth-promoting substances (Clouse and Sasse, 1998). The authors found that depending on the assay system, BS elicits a wide range of biological activities including both growth promotion and inhibition. Korableva *et al*. (2002) reported that post-harvest application of 2, 4-epibrassinolide prolong tuber dormancy and increase ABA content and ethylene production. However, the effects BS content and activities on dormancy status have not been reported and, as such, the role of this interesting class of regulators in tuber dormancy remains speculative. According to Burton and Meigh (1971), potato tubers produce a number of volatile

compounds; several of these volatiles are potent growth inhibitors. Subsequent studies identified several bioactive volatiles including the 1, 4- and 1, 6- isomers of dimethyl-naphthalene (Meigh *et al*., 1973). Application of these dimethyl-naphthalene derivatives results in a transient inhibition of sprout growth, and a commercial product containing these isomers has been marketed for post-harvest sprouts control (Lewis *et al*., 1997; Prange *et al*., 1997).general and potato in particular.

3. Summary and Conclusion

In Ethiopia, potato is one of the most widely used vegetable crops in human diet. It is also an important cash crop for farmers in the mid and highlands of the country, where it is grown abundantly. However, lack of quality planting materials among growers is a limiting factor adversely affecting the production and productivity in these areas. Conversely, identifying appropriate management practices to improve the quality of planting materials is a priority tointroduce plant growth regulators for potato producers. Both methods of treatments have effect on breaking dormancy, early emergence of shoots, increased tuber yield and quality of potato Haulm applications of GA3 at 750 and 1000 ppm reduced dormancy period by 24 days and 27days, respectively. It also hastened early physiological maturity, increased average sprout number and sprout length of tubers, respectively. Similarly, dipping treatment of 40 and 50 ppm reduced dormancy period by 18 days and 20 days, respectively, and had more effect over the control than lower concentrations. Haulm application of 750 or 1000 ppm reduced days to emergence by 11 days while dipping of seed tubers in 40 and 50 ppm reduced days to emergence by 6 and 8 days, respectively.

Haulm applications of 750 and 1000 ppm GA3 increased tuber yield per hill by about 26% and 45%, respectively as compared to untreated tubers. In response to haulm application of 750 and 1000 ppm GA3, total tuber yield per ha increased by about 37% and 48%, respectively. Similarly, haulm application of 750 and 1000 ppm of GA3 increased marketable tuber yield by about 39% and 48% above the control, respectively. In addition, haulm application of GA3 at a concentration of 750 or 1000 ppm increased dry matter content by about 15% compared to the control while 13% dry matter content was obtained in response to dipping the seed tuber in 50 ppm GA3 solution. Regardless of the concentration, haulm application of GA3 increased specific gravity by about 2% as compared to the control. Moreover, dipping seed tubers in 50 ppm of GA3 solution increased the tuber specific gravity of the next generation by 1.3% as compared to the control. Although the experiment was conducted in one location and season using a single cultivar it is reasonable to point out that foliar application of gibberellic acid one week before harvest resulted in shortened dormancy period, increased sprout mass and improved both yield and quality of the subsequent potato generation.

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